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Subject: Chambers Creek hatchery winter steelhead in the Elwha River

What are the risks and benefits to native populations of *O. mykiss* in the Elwha River to the continued use of Chambers Creek steelhead, a non-local stock?

Continued use of Chambers Creek hatchery steelhead in the Elwha River would increase the risk of loss of genetic variation and loss of fitness in native steelhead.

Genetic changes associated with artificial propagation are inevitable. Selective regimes and mortality profiles differ so dramatically in natural and cultured populations that some genetic change cannot be avoided. Thus the use of any hatchery-derived population should be carefully considered. The Chambers Creek Hatchery population was derived from a South Puget Sound population and subjected to multiple generations of deliberate selection, making it a particularly unsuitable candidate for use in the Elwha River Basin.

The key question is: What are the consequences of the continued release of Chambers Creek hatchery steelhead for the recovery of natural *O. mykiss* population(s) in the Elwha River? A large body of empirical information now documents reduced fitness of hatchery fish, including steelhead, in nature compared to their wild counterparts, and the fitness reductions increase as a function of the number of generations in hatchery production. Because of the history of propagation and selection in Chambers Creek hatchery steelhead (see **Supporting Material**), the primary risks posed by the introgression of these fish into native fish populations in the Elwha River are genetic: loss of diversity within populations, loss of diversity among populations, and loss of fitness. That said, there is the potential for considerable ecological risk to native fish in the Elwha River posed by Chambers Creek hatchery steelhead as well (see below).

Loss of diversity within populations

Genetic diversity within populations provides the raw material for evolution. Populations with low levels of genetic variability have less capacity to respond to changes to their environments. This applies to both long-term climatic changes and short term oscillations. Interbreeding between hatchery and wild fish, especially when wild abundance is low, can actually reduce genetic diversity by increasing (through differential survival of hatchery and wild fish) the frequency of "hatchery" genes in naturally spawning fish.

The best way to ensure that within-population genetic diversity is not seriously compromised by hatchery fish production is to ensure that the fraction of natural spawners that are derived from the hatchery program is very small.

Loss of diversity among populations

Genetic diversity among populations confers resilience to natural systems on a variety of temporal and spatial scales. In the short term, a diverse array of natural populations helps buffer the species as a whole from natural fluctuations in environmental conditions. A species with diverse natural populations that express a range of phenotypic and life history traits will generally have some populations that have normal productivity even under anomalous environmental conditions. In contrast, a species that has been constrained to one or a few widely-distributed life history strategies will have a more uniform response to environmental variation, leading to larger amplitude variation in abundance and productivity.

The major concern regarding loss of among-population diversity is that widespread natural spawning of hatchery fish derived from a broodstock with low genetic and phenotypic diversity will lead to replacement of locally adapted populations with fewer, relatively homogeneous ones.

By far the best way to minimize this risk is by limiting natural spawning by hatchery fish.

Loss of fitness

Hatchery production can lead to loss of fitness in wild populations when they interbreed with hatchery fish. The fitness loss can occur through either or both of two mechanisms. Domestication leads to genetic changes in a hatchery population that can be passed on to wild populations by natural spawning of hatchery fish; outbreeding depression can occur when genetically differentiated hatchery and wild populations interbreed—as might happen, for example, if non-local populations are used for broodstock and some of these fish reproduce in the wild.

The most reliable way to ensure minimal effects on wild fish fitness is to limit natural spawning of hatchery fish. If this is unavoidable, then two general strategies are available to attempt to minimize the fitness consequences of interbreeding between hatchery and wild fish. In one strategy, often used in integrated hatchery programs, efforts are made to keep a hatchery population as similar as possible genetically to the wild population. This would require using local fish for broodstock and making efforts to reduce the rate of domestication. Under this strategy, it is difficult to achieve some of the benefits to production and/or cost efficiency that can result from intentional selection for traits that are desirable in cultured populations but probably maladaptive in the wild. The use of Chambers Creek hatchery steelhead in the Elwha River would essentially preclude this strategy especially when there is a locally-derived broodstock that is available to service both recovery and mitigation needs.

Another strategy, adopted by some isolated hatchery programs, takes the opposite approach: make the hatchery population substantially different genetically and phenotypically from the local wild population, which might be accomplished by using non-local (and perhaps not locally adapted) sources for broodstock and/or intentionally selecting for traits that are considered beneficial for harvest management or culture considerations. This situation reflects one of the original purposes behind development of the Chambers Creek hatchery steelhead broodstock. The logic behind this strategy is that if the hatchery population is highly domesticated or otherwise maladapted to local conditions, opportunities for interbreeding are substantially reduced and harvest can target hatchery fish through timing or other factors. By definition, isolated hatcheries limit introgression, by limiting the proportion of hatchery fish spawning in the wild to a maximum of 5% of the naturally spawning population. It is not clear and highly unlikely that the current hatchery program in the Elwha River meets this criterion. Unfortunately, any hatchery fish that successfully breed in the wild may produce offspring with characteristics that are maladaptive in the wild.

Other risks

A comprehensive risk-benefit analysis should consider a number of related, primarily ecological, risks; we briefly list some prominent ones below.

Competition/predation. Hatchery fish can compete with natural fish for food, territory, spawning sites and access to mates. If the number of hatchery fish is sufficiently large, their presence may impose other forms of selection that can alter characteristics of wild populations important to survival and reproductive fitness.

Disease and other mortality factors. Risks of introduced pathogens and parasites include temporary epidemics and/or long-lasting population reductions and even extinction of wild populations. Risks posed by disease agents seem to be harder to quantify than those for competition/predation, as a single individual transferred to a recipient population can have dramatic consequences.

Low power to detect adverse effects. Because natural variability in most natural populations is relatively high, the ability to detect deleterious effects of hatchery fish can be low, even in ambitious, well-designed programs. This is likely to be especially true early in a production program. What this means is that by the time adverse effects are detected, it is likely that they will have already occurred and might have profound and long-lasting consequences for natural populations.

Uncertainty. The only certainty is that unexpected things will occur as both wild and hatchery steelhead attempt to access newly available habitat. If the benefits will only be realized if everything goes exactly as planned, the program will have little realistic prospect for success and adverse consequences for natural populations will likely be underestimated.

Programmatic inertia. Experience with fish hatchery programs indicates that, once begun, hatchery programs can be difficult to stop even if there is compelling biological evidence regarding their ineffectiveness or their adverse impacts on natural populations. Therefore, a key question in considering whether to initiate a hatchery supplementation program is, Can the program be terminated or modified if a biological evaluation indicates its costs and/or detrimental effects are greater than its benefits?

Continued use of Chambers Creek hatchery steelhead in the Elwha River would provide no tangible benefits to native steelhead.

Risks and benefits are best evaluated in the context of the program goals one is trying to achieve. The primary goal for native Elwha River steelhead is sustainable natural production of locally adapted fish throughout the accessible parts of the basin, including the upper river currently blocked by dams. In the ESA listing of Puget Sound steelhead, Chambers Creek Hatchery winter steelhead were specifically excluded from the Puget Sound steelhead Distinct Population Segment (DPS), because the long-term genetic effects of selection and domestication have led to considerable divergence in life history. In short, Chambers Creek fish cannot contribute to the recovery of the DPS. While the current Chambers Creek fish do provide harvest opportunity in the lower Elwha River, this harvest benefit cannot compensate for the potential risks to recovery of the population and the DPS.

Do the risks and benefits change because dam removal will take place in the next several years?

Dam removal provides an opportunity for Chambers Creek hatchery steelhead to affect natural colonization of the upper Elwha River by native steelhead.

Simultaneous removal of the two large dams on the Elwha River is slated to begin in 2011. The Elwha River poses a unique opportunity because dam removal will allow existing native salmon and steelhead populations to access and recolonize nearly pristine habitats above the dams in Olympic National Park. There will be interactive effects as extant resident salmonid populations above the dams are exposed to anadromous colonizers, and as resident salmonids are able to freely migrate downstream (Brenkman *et al*. 2008b). Steelhead are likely to colonize the majority of mainstem, floodplain, and tributary habitat made available to them with dam removal due to their initial population size and run timing, ability to maneuver past natural barriers in the canyon reaches, and their propensity to utilize alluvial valley bottoms and tributary habitats. Distance to a source population for steelhead is short because they already occur in relatively large numbers below the dams. In addition, there is a self-sustaining population of resident *O. mykiss* above the dams (Brenkman *et al*. 2008b) which could be an important contributor to the recolonization of anadromous *O. mykiss* due to interbreeding (Seamons *et al*. 2004, McMillan *et al*. 2007).

Steelhead are highly freshwater-dependent, and their ability to utilize the newly opened mainstem, floodplain, and tributary habitat should be considerable. Larger tributaries in the uppermost portion of the upper Elwha such as Hayes, Lillian, Lost, and Goldie, offer low gradients that could be utilized by steelhead. The middle Elwha could also have rapid tributary colonization by steelhead due to the greater proportion of low gradient tributary habitat relative to mainstem and floodplain habitat. For example, the Little River, a major tributary of the middle Elwha River, may see steelhead play a dominant role in recolonization because it is currently dominated by resident rainbow trout. Pess *et al*. (2008, 2010) hypothesized that salmon and steelhead colonization in the Elwha River will occur, and self sustaining populations are likely to become established, within years to up to three decades after dam removal. Response will vary by species, initial source population size, distance to a source population, habitat area, straying rate, run timing and their ability to negotiate short-term turbidity increase, adaptability to local habitat characteristics, and interactions with existing fish populations.

Do Chambers Creek steelhead have a role in the recovery of native Puget Sound steelhead? If so, what is it?

In our opinion as Northwest Fisheries Science Center scientists, Chambers Creek hatchery steelhead have no role in the recovery of native Puget Sound steelhead.

Biological Review Teams and Technical Recovery Teams have focused on naturally produced, native-origin fish as the definitive unit in measuring population viability. While some artificial population programs may contribute to the recovery process it is presumed that these programs would utilize native-origin founding stocks, where available, and are ultimately designed to assist in reestablishing natural reproduction. The Biological Review Team that evaluated the status of Puget Sound steelhead in 2007 concluded that Chambers Creek hatchery steelhead posed a risk to the diversity of this Distinct Population Segment (Hard *et al.* 2007).

The continued release of non-native Chambers Creek winter run steelhead into the Elwha Basin is likely to reduce the viability of the naturally produced winter steelhead there (these are presumed to be of native origin). At best, an isolated Chambers Creek hatchery program would have no effect on population viability, although it is not clear that it would be possible to operate a truly isolated program. Off-station releases of Chambers Creek steelhead are likely to compete with juvenile wild steelhead and, in spite of the presumed temporal differences, there is a potential for spawning interaction and introgression. Since the Chambers Creek hatchery stock is not part of the listed DPS, it cannot be considered as a useful substitute for the existing “native” population. Based on established viability criteria it is difficult to imagine a scenario where the release of Chambers Creek fish would not impede the recovery of the Elwha River population of steelhead. Although the Puget Sound steelhead Technical Recovery Team’s identification of demographically independent populations (DIPs) and major population groups (MPGs) is not complete for Puget Sound steelhead, because of its prominence in the western portion of the Puget Sound DPS the Elwha River population will likely play a prominent role in any recovery scenario. Thus, continued use of Chambers Creek fish would only serve to delay the ultimate recovery of the Puget Sound DPS.

Supporting Material

Background

The Chambers Creek winter-run steelhead stock was founded in the 1920s from the collection and spawning of native adult fish trapped in Chambers Creek, a south Puget Sound tributary. The propagation of Chambers Creek steelhead at this location occurred through 1945, when a new steelhead rearing program was initiated, leading to marked changes in this stock. In this new program, adult steelhead captured in Chambers Creek were transferred to the South Tacoma Hatchery in the upper watershed, where relatively warm water (12ºC) was available to accelerate spawning maturation time. Additionally, the earliest maturing fish were selected for propagation. Continuous year-to-year use of these practices, combined with the warmer water and nutritional advances provided by newly developed dry diets, allowed the production of smolts in one year instead of two. The first hatcheries outside the Chambers Creek watershed to use this stock were located on the Green and Puyallup rivers and on Tokul Creek. The progeny of adult returns established through transplants of Chambers Creek hatchery fish to these and other Puget Sound hatchery release sites were transferred back to Chambers Creek when needed to offset egg take shortfalls, and were incorporated back into the winter-run steelhead population maintained at the site. However, as a standard practice, Chambers Creek was maintained as the sole annual source of eggs for other hatcheries.

Chambers Creek Hatchery, originally a private trout hatchery, was purchased by the Washington Department of Game in 1972 and rebuilt. This hatchery was subsequently used to propagate and further develop the Chambers Creek winter-run steelhead stock and became the major source of winter-run steelhead broodstock for western Washington. Chambers Creek-derived winter-run steelhead have been propagated and released from most Puget Sound steelhead facilities, including Reiter Ponds, Tokul Creek, Wallace River, Dungeness, Bogachiel, Hurd Creek, Eells Springs, Kendall Creek, McKinnon Ponds, Samish, Lake Whatcom, Puyallup, Soos Creek, Voights Creek, Marblemount, Barnaby Slough, Grandy Creek, Fabors Ferry, Baker River, Davis Slough, Whitehorse Ponds, Arlington, and the Chambers Creek facilities. Most of the programs using this transplanted stock are still active.

The original goal of the Chambers Creek program was to produce an early returning adult steelhead that smolted after one year. By the mid 1970s, it was concluded that the advanced adult spawn timing selected to meet the yearling smolt objective created temporal separation in natural spawning areas between Chambers Creek hatchery winter-run and native late- winter-spawning steelhead, reducing the likelihood of interbreeding.

Elwha hatchery winter steelhead stock is derived from a variety of sources, with the primary stocks being Chambers Creek and Bogachiel (Puget Sound derivatives). This program has been maintained with adult returns to the Lower Elwha Hatchery since 1977. The objective of the hatchery program is to provide for harvest, while conserving winter steelhead in the Elwha River. The early spawn timing of this stock, achieved through long-term selection on spawn timing, was intended to minimize genetic interaction with naturally spawning winter steelhead throughout Puget Sound. It has long been argued that interbreeding of the hatchery stock with the naturally spawning stock is minimized by their differences in spawn timing.

The original Chambers Creek winter-run steelhead stock was collected from native returns to Chambers Creek, with the likelihood of significant genetic changes due to selection for early maturation. Smolts originating from adults returning to the Green (Soos Creek), Nemah, and

Samish rivers have apparently been released into Chambers Creek, so this stock probably has a rather complicated genetic background. The mixture has proven adaptable to Puget Sound streams, at least in terms of adult returns. By 1979, as much as 90% of the total catch in some streams was attributable to plants of Chambers Creek stock. Effective population size is not known due to pooling of gametes during spawning at Chambers Creek. Historical genetic data for the original Chambers Creek stock allowing for quantification of this divergence are lacking, but differences imposed in run, spawn, and smolt emigration timing for the Chambers stock would support the hypothesis that there have been attendant, major genetic diversity changes in the population.

Winter-run steelhead returned to Chambers Creek Hatchery from mid-December to February. The original winter-run steelhead population in Chambers Creek has been subjected to purposeful selection for over six decades, and is very likely more than moderately diverged from the donor native population.

Although the Chambers Creek Hatchery winter-run steelhead broodstock was initially established using local origin adults, during its 2007 status review of Puget Sound steelhead the Biological Review Team considered the intentional and unintentional selection of life history traits as a major factor in its evaluation (Hard *et al.* 2007). The advancement in run and spawn timing of the Chambers Creek winter-run steelhead (almost two months) has dramatically altered the reproductive connectivity between the hatchery-origin and naturally spawning adults. Additionally, the sole use of hatchery-origin fish for hatchery broodstocks greatly increases the potential for hatchery domestication. Comments provided by WDFW suggest that Chambers Creek winter-run steelhead have a poor rate of natural spawning success.

The Hatchery Science Review Group (HSRG), in its report on Puget Sound hatchery salmon and steelhead programs, noted that a segregated hatchery program culturing this early running, non-native broodstock is inconsistent with long-term conservation goals for steelhead in the Elwha River (HSRG 2006). The HSRG also stated its contention that Chambers Creek stock steelhead is an inappropriate stock for recolonization of the upper watershed. (Although the Chambers Creek stock is not intended to be used for recolonization, it is likely given the large number of fish released that some Chambers Creek fish will migrate to the upper Elwha River and influence recolonization.) The Elwha Restoration Plan for steelhead in the basin has reached the same conclusion, and further argued that a relatively large number of hatchery smolts released would pose significant risk to a native population that may be residualized above dams and used as a possible core for recolonization.

The HSRG suggested that a plan for the recovery of steelhead in the Elwha River following the removal of two dams include contingencies for custody of the genetic resource under different environmental scenarios, including a schedule for disposition of returning adults as a function of run size. The HSRG has also urged the managers to consider the out-planting of adults into the upper watershed as a part of the recovery strategy. The plan should also emphasize the critical importance of monitoring and evaluation as a key component of a strategy for success. Additional consultation between the Elwha Recovery Team and the HSRG would likely be beneficial for development and refinement of the restoration and recovery plan. State and tribal comanagers generally agreed with the HSRG’s recommendations, and have considered alternate broodstock sources for use in the Elwha Restoration Plan. If a conservation program is desired, the HSRG concluded that it would need to be considered separately, using a more appropriate broodstock.

The Elwha Report (1994) states that hatchery production of steelhead is necessary to maintain genetic integrity of Elwha River steelhead until habitat productivity is restored. However, the Report recommended establishing a regional system of "wild steelhead management zones," consistent with restoration plans for the Elwha River, where streams are not planted with hatchery fish and are instead managed for native stocks. The Report further recommended analysis of benefits versus risks on outplanting hatchery steelhead in freshwater habitat.

Recent work by Brenkman *et al*. (2008a) and Winter and Crain (2008) provided a cursory summary of spatial and temporal plantings of hatchery fish over the last century. From 1953 to 2006 a total of approximately 3.5 million winter steelhead trout, and 0.5 million summer steelhead trout were released into the lower Elwha River. Review of historic records from the early 1900s to the 1950s revealed that at least 165,000 winter steelhead have been released upstream of Glines Canyon Dam (Schoeneman and Junge 1954; James River 1988; Lower Elwha Klallam Tribe and Olympic National park, unpublished data). Winter steelhead releases are comprised of Chambers Creek stock and most recently, natural-origin captive brood steelhead are being reared and released. There are currently two hatchery facilities in the Elwha River administered by Washington Department of Fisheries and Wildlife (WDFW) and the Lower Elwha Klallam Tribe (LEKT) that have operated since 1976 and 1978, respectively. The hatcheries have focused on supplementation of salmonids below Elwha Dam and preservation of remnant fish populations, particularly Chinook salmon (Winter and Crain 2008). The State hatchery produces Chinook salmon and releases 2,700,000 yearlings and sub-yearling Chinook salmon. The tribal facility focuses on coho salmon and steelhead and annually releases 120,000 winter steelhead. The reliance on hatchery operations for Elwha salmon restoration varies with each species. In general, the proposed restoration strategies rely on the combination of hatchery enhancement and natural recolonization.

Recent work by Winans *et al*. (2008) has shed considerable light on the influence of hatchery operations in the Elwha River Basin. Based on pooled data from independent studies, it was observed that native in-river steelhead were distinguishable from existing hatchery stocks being released. Winans *et al*. (2008) concluded that given the various levels of genetic distinctiveness of Elwha populations, there was still a native steelhead component in the Elwha and thus it will be important to manage and monitor the genetic aspects of recolonization of the Elwha River.

Studies of effects of hatchery on wild salmonids

There have been a number of papers addressing the issue of domestication and the potential loss of fitness in hatchery-reared salmonids. Early research by Reisenbichler and McIntyre (1977) and more recently Araki *et al.* (2009) are among a growing number of empirical studies of the deleterious effects of hatchery propagation on fitness in the wild. Studies by Lynch and O'Hely (2001) and Ford (2002) have focused on the theoretical genetic mechanisms for this reduction in fitness. Reisenbichler and Rubin (1999) discussed both genetic and non-genetic effects that could produce declines in the abundance and productivity of natural populations as a result of hatchery supplementation. For example, hatchery fish can decrease productivity of natural populations through competition for resources. Kostow and Zhou (2006) estimated that the presence of hatchery origin summer-run steelhead in the Clackamas River depressed the productivity of the native winter-run by 22%. In their review of 22 supplementation programs, Waples *et al*. (2007) were unable to determine whether supplementation programs were able to provide a long-term benefit to natural populations, largely, in part, due to the absence of sufficient monitoring. In its recent review of the scientific foundation for salmon hatchery reform, the Recovery Implementation Science Team (RIST 2009) concluded that "there were some indications that steelhead hatchery stocks propagated for many generations had particularly low relative fitness."

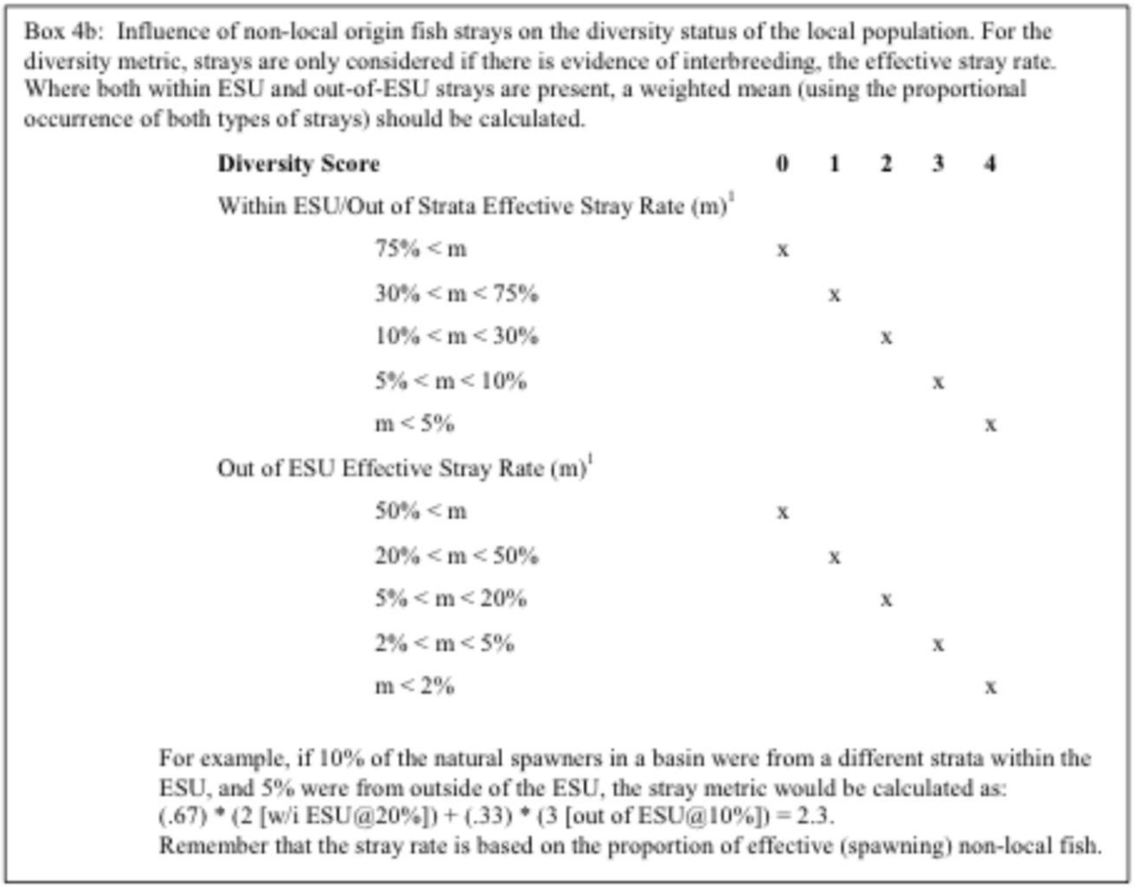
In general, there are three likely stages where hatchery-origin (domestication) effects could be expressed: smoltification success and emigration survival, spawning success, and post-fertilization survival. Studies on the reproductive success Skamania Hatchery summer run steelhead introduced into the Kalama River (Chilcote *et al*. 1986, Leider *et al*. 1990) and the Clackamas River (Kostow *et al*. 2003) suggests that hatchery-origin fish are less fit than native naturally-produced fish. In the Snake River Basin, smolt to adult survival rates (SARs) for transported hatchery-origin and wild steelhead juveniles averaged (geometric mean) 0.91% and 1.56%, respectively (CSSOC and FPC 2007). Even with this differential return rate, a substantial number of hatchery-origin adults would potentially be returning to the stream they were released into. Returning hatchery-origin adults may be at a further disadvantage in mate selection, spawning site quality, spawning success, and/or the early survival of subsequent progeny. Reduced spawning success has been observed in captively reared Chinook salmon (*O. tshawytscha*) that were allowed to spawn naturally (Berejikian *et al*. 2001). Although this study likely represents an extreme in hatchery rearing effects, the low egg deposition rate (49.5%), low egg to fry survival (62.5%), and high level of nest abandonment (40%) reported in this study would result in a dramatic decline in overall fitness relative to naturally-reared fish. Overall, hatchery-origin fish appear to have lower smolt to adult survival rates, lower spawner success, and low levels of introgression.

Previous Technical Recovery Team Determinations of Hatchery Influence on Viability

The potential effects of using non-native stocks of fish on population viability were addressed by the Willamette and Lower Columbia River Technical Recovery Team (TRT) in their Viability Criteria document (WLCTRT 2006). Specifically, hatchery interaction effects were included in the diversity score for each population—these effects included both introgression (loss of local adaptation) and competition:

Within-population diversity (WLCTRT 2006):

Local adaptation can also be affected by the introgression of non-native spawners into naturally- spawning populations. Historically, some level of interbreeding certainly existed between populations; however, the establishment of hatchery populations using non-native broodstock sources and the disruption of migratory paths due to habitat degradation has likely increased the degree of gene flow between populations by several fold. The more distant the relationship between a population and the source population of the straying fish, the less likely that the straying fish will contribute genes that are beneficial to the receiving population. Thus, stray fish from a population within the ESU, but from a different strata, are likely to have a smaller deleterious effect than fish straying in from outside of the ESU. Alternatively, the more distinct the stray fish are from the receiving population the less likely they are to interbreed with local fish (because of differences in spawn timing, body morphology, or other behavioral characteristics). It should be underscored that there are other potential effects from straying fish not directly related to the diversity criteria.



Box 4b: Influence of non-local origin fish strays on the diversity status of the local population. For the diversity metric, strays are only considered if there is evidence of interbreeding, the effective stray rate. Where both within ESU and out-of-ESU strays are present, a weighted mean (using the proportional occurrence of both types of strays) should be calculated.

Diversity Score	**0**	**1**	**2**	**3**	**4**
Within ESU/Out of Strata Effective Stray Rate (m)[1]					
75% < m	x				
30% < m < 75%		x			
10% < m < 30%			x		
5% < m < 10%				x	
m < 5%					x
Out of ESU Effective Stray Rate (m)[1]					
50% < m	x				
20% < m < 50%		x			
5% < m < 20%			x		
2% < m < 5%				x	
m < 2%					x

For example, if 10% of the natural spawners in a basin were from a different strata within the ESU, and 5% were from outside of the ESU, the stray metric would be calculated as:
(.67) * (2 [w/i ESU@20%]) + (.33) * (3 [out of ESU@10%]) = 2.3.
Remember that the stray rate is based on the proportion of effective (spawning) non-local fish.

Similar concerns were voiced by the Interior Columbia TRT (ICBTRT 2007, p. 62):

> Natural breeding groups of Pacific salmon and trout (*Oncorhynchus* spp.) tend towards maintenance at natal localities because of strong homing capabilities coupled with localized adaptations (NRC 1996, Hendry and Quinn 1997, Hendry *et al*. 1998, Reisenbichler *et al*. 2003). Stability of such aggregates over generations through centuries, and as fine as the local reach (Gharrett and Smoker 1993, Bentzen *et al*. 2001), is influenced by numbers of returning natal individuals (Waples 2004), ecological variability (Montgomery and Bolton 2003), and gene flow from exogenous fish (Utter 2001). This spatial and potentially adaptive level of variability within and between populations is recognized as important and necessary for viability of salmonid populations (McElhany *et al*. 2000).
>
> The stability of salmonid population structure can be undermined by effective straying from returning hatchery releases and natural-origin strays induced by anthropogenically altered conditions. Such increases of gene flow above natural levels are counterproductive to recovery efforts within listed ESUs because of hatchery adaptations or domestication (Epifanio *et al*. 2003, Waples and Drake 2004), losses of genetic variability through supportive breeding (Ryman and Laikre

> 1991, Wang and Ryman 2001), and erosions of natural population structure such as homogenization (Utter 2005). The ultimate impact of these increases in gene flow is dependent upon the duration of the increase, the proportion of exogenous spawners, and the origin of those spawners.

The ICRTRT (2007) developed a diversity metric to assess the potential influence of non-native fish on the viability of the naturally-produced native population:

> We have developed a flow-chart approach to assigning risk associated with exogenous spawners in salmonid populations (Figure 9). Our approach is sequential, and evaluators should consider exogenous spawners in their population in the sequence laid out. Our approach considers the source of the exogenous spawners first, providing increasing tolerance for both proportion and duration of exogenous spawners the more closely related they are to the population of interest. For exogenous spawners derived from the local population, we then consider the type of hatchery program from which those spawners were derived, allowing greater input from hatcheries using "best management practices." Rather we suggest that hatchery programs that conform to the principles described in recent publications (e.g., Flagg *et al*. 2004, Olson *et al*. 2004, Mobrand *et al*. 2005) could be considered to have "best management practices." These will change over time as our understanding of the impact of hatchery management practices on genetic, phenotypic and fitness characteristics increases. Main components of the program to be considered include brood stock selection, efforts to minimize within-population homogenization, actions to prevent domestication or other in-hatchery selection, breeding protocols, rearing and release protocols and other efforts to minimize effects on population structure and fitness components. Future assessments should consider advancements and updates in hatchery science when determining which category a particular program should be ascribed to.
>
> These criteria are generally consistent with other efforts to quantify risk from hatchery origin spawners (Mobrand *et al*. 2005). However, we do encourage case-by-case treatment of conditions that may affect the risk experienced by the population. For instance, if exogenous spawners are localized within a large, complex population, leaving the bulk of the population unaffected, a somewhat higher proportion and/or duration of those exogenous spawners could be associated with a lower risk level. Similarly, in a very diverse MPG, the presence of exogenous spawners derived from a highly divergent population (even within that same MPG) might merit higher risk levels than shown. While we offer this flexibility, such situations should be well-documented and justified.
>
> There are several more detailed considerations for applying our criteria. First, when assessing the current status of a population, conditions in the most recent three generations should be considered. Second, the proportion of spawners belonging to a category should be calculated using the total number of spawners in the denominator. Third, if there are multiple sources of exogenous spawners within a single population, the total proportion of exogenous spawners should be considered. In general, the highest risk level assigned to any of those sources should be used for this metric, unless there are two or more "moderate" rated sources, in which case a

> risk level of “high” should be used. However, there may be situations where spawners from each source would yield individually a low rating, but the total proportion of exogenous spawners is relatively high. In these cases, the risk rating should be increased appropriately to either moderate or high. Fourth, there may be cases where population specific estimates of the hatchery origin proportion of spawners are not available but circumstances indicate relatively high hatchery contribution rates are likely (e.g., nearby major release site, evidence for straying into other nearby natural areas). The risk rating applied in those cases should reflect the potential contribution levels of hatchery spawners. Finally, we do not extend our criteria beyond 5 generations for any source of exogenous spawners, because there is considerable uncertainty about the long-term impacts of this unnatural gene flow. We anticipate that future research will allow these criteria to consider longer time periods more robustly.

This metric offers the opportunity to contribute to planning efforts as well as to evaluate current risk. Conservation and/or supplementation programs may be desirable to mitigate short-term extinction risk, for example. In these cases, this metric provides a transparent means to plan and coordinate recovery efforts to minimize the risks from such a program.

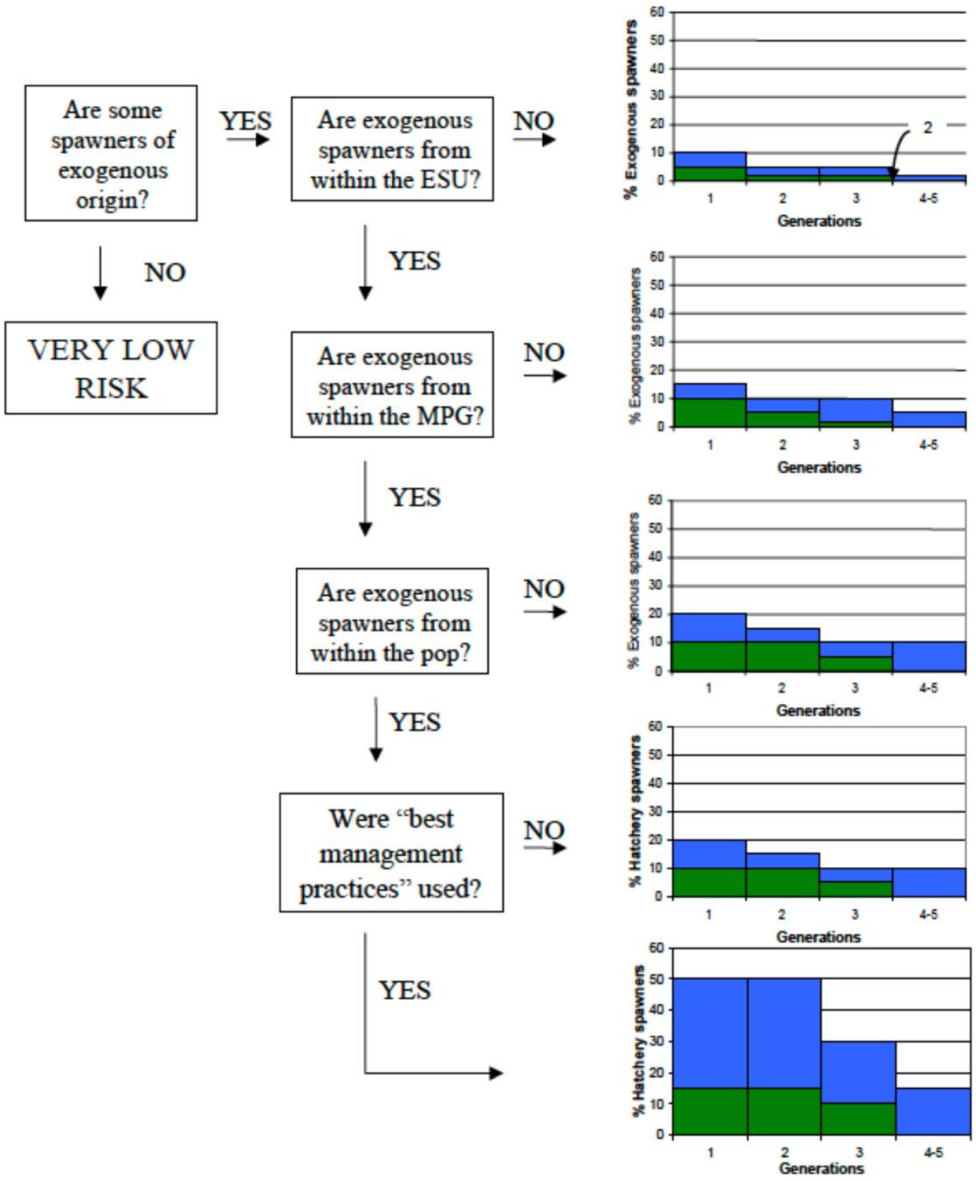


Figure 9 (ICRTRT 2007). Risk criteria associated with spawner composition for viability assessment of exogenous spawners on maintaining natural patterns of gene flow. Green (darkest) areas indicate low risk combinations of duration and proportion of spawners, blue (intermediate areas indicate moderate risk areas and white areas and areas outside the graphed range indicate high risk. Exogenous fish are considered to be all fish hatchery origin, and non-normative strays of natural origin (see text).

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